03 Solids, Liquids and Gases

Introduction

This chapter looks at some of the macroscopic properties of the three states of matter and seeks to provide explanations in term of the kinetic theory of matter and particulate models. It also discusses the important idea that in science, theoretical knowledge accumulates and becomes more precise by the modification or replacement of existing theories and models when they are unable to explain new observations or predictions. Links can be made with ideas introduced in Introduction: Chemistry as an Inquiry in the textbook.

Chapter Opener (page 30)

1. To open the chapter, the following questions could be discussed. Precise answers are not needed at this stage.

   ***What is matter?* Students will have learnt the meaning of matter in Lower Secondary Science. Refer to page 32 for the definition.**

   What is meant by the word 'property'? What properties do solids, liquids and gases have?

   Answer: The word 'property' means 'what something is like' (see page x of Introduction in the Textbook). For common properties of solids, liquids and gases, refer to page 32.

   What is a model? Why do scientists use models?

   Answer: A model consists of anything that helps our understanding of the idea, e.g., words, diagrams, physical models, formulas and equations.

2. Carry out an 'Inquiry Preview.'

Teaching Notes for

ChemMystery (page 31)

Why do pollen grains move about in water

Initial Investigation

- Scientists did not have a complete model of matter. The main reason was that in his day, it was not suspected that particles of matter were in constant random motion.
- A hypothesis is a tentative explanation for an observation, phenomenon, or scientific problem. To be accepted it must be tested experimentally and be able to account for the results of the experiments.
- A theory.

Notes for Teachers

The first half of the 19th Century was a period when scientists from different disciplines, such as zoology, botany and geology travelled from Europe to the Southern hemisphere to make observations and collect data and specimens. This resulted in many important ideas in Science. Robert Brown was among this group of scientists and his work resulted in the kinetic particle theory of matter. Other eminent fellow-travellers were Charles Darwin and Alfred Wallace whose work lead to the development of the theory of evolution.

Learning Outcomes

After completing this chapter, students should be able to:

- describe the main properties of solids, liquids and gases
- describe and explain the movement of particles in liquids and gases
- explain everyday examples of diffusion in terms of particles
- state the quantitative effect of particle mass on the rate of diffusion and explain the effect of temperature on the rate of diffusion
- explain the interconversion of states of matter in terms of the kinetic particle theory and the energy changes involved

Teaching pointers

3.1 What is Matter and What are its Different States? (page 32)

1. A bus is an example of a familiar object that contains parts that can be classified into the three states of matter. Some examples are as follows:

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Solids	Liquids	Gases
Body	Petrol	Air in the tyres
Seats	Oil	
Engine	Water (all used in the engine)	

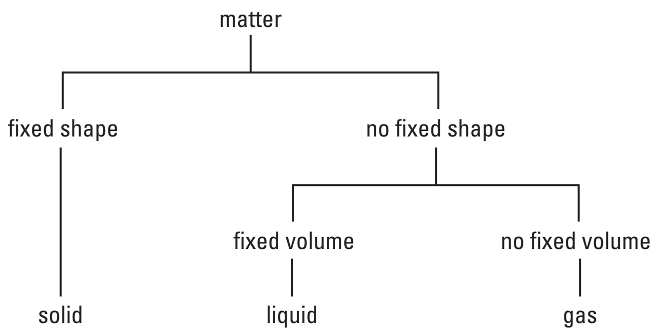
2. Using actual solids, liquids and gases, demonstrate the physical properties of shape, volume, compressibility and ability to flow. For example:

- Squeezing a solid to show that solids cannot be compressed.
- Pouring water from one container to another to show that liquid flows and changes its shape but not its volume.
- Compressing air in a balloon or gas syringe to show that gases can be compressed.
- Placing a drop of liquid bromine in a sealed flask to show that as it evaporates, the bromine vapour fills the flask.

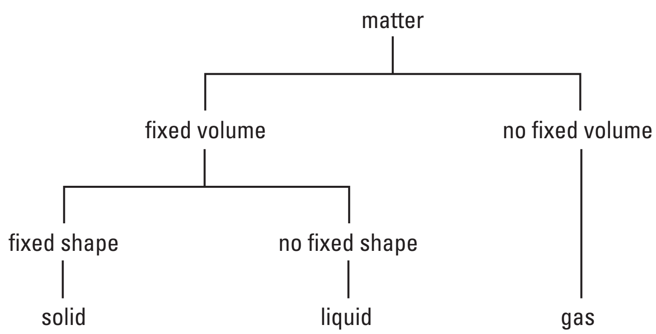
3. In the case of the bus, for each part, link the common properties of the state of matter to how the part is being used. Solids are used because they are rigid (do not flow) and keep their shape. Liquids are used because they flow. Gas is used in the tyres because it can be compressed and absorb shock.

4. Teachers might ask the class to make a key to classify matter according to the properties in Table 3.1 on page 32 of the textbook. Here are two such keys:

(a)



(b)



Stimulation

One possible introduction is to bring a collection of common solids and liquids into the classroom. Discuss the meaning of matter and its classification into three states. A variety of physical properties of these objects could be discussed such as shape, colour, smell, hardness. From this, discuss the physical properties common to each of the states of matter and the properties of volume, shape, compressibility and flow that are used to define and classify them. Some of the 'Skills Practice' questions could be incorporated into the discussion.

Note: Point out to students that the word 'matter' in the context of chemistry is an uncountable noun and so is used in the singular form without an article.

Skills Practice (page 32)

1. **(a)** For example, differences in density, hardness, flexibility, heat/thermal conductivity, electrical conductivity, melting points.
   (b) For example, differences in colour, heat/thermal conductivity, electrical conductivity, boiling points.
   (c) For example, differences in smell, colour, density, heat/thermal conductivity.
2. **(a)** A liquid takes the shape of its container as it flows and has no fixed shape.
   (b) A gas flows in all directions and has no fixed shape or volume.
3. For example, fill a 25.0 cm^3 pipette. Transfer the water to a measuring cylinder — the water flows. The water in the measuring cylinder has a different shape than in the pipette but its volume is still 25.0 cm^3.

Notes for Teachers

Definitions of a solid, a liquid and a gas

These can be defined in terms of their shape and volume. Here is one possible set of definitions.

Solid: A substance with a definite shape and a definite volume (at a given temperature).

Liquid: A substance with a definite volume but no definite shape (at a given temperature).

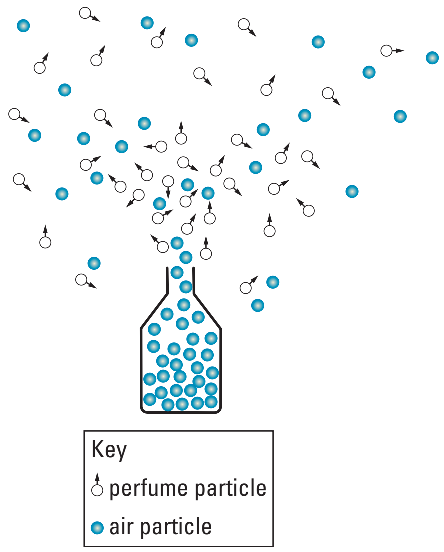
Gas: A substance with neither a definite shape nor a definite volume (and fills any container it is placed in).

Teaching pointers

3.2 How Did the Kinetic Particle Theory of Matter Come About? (page 32)

1. Revise the meaning of a theory (refer to page xiii of the Introduction in the Textbook). The idea that matter is made up of extremely small particles contrasts with our macroscopic experience of matter as being continuous i.e. without any breaks or spaces. Thus water, for example, appears smooth and does not have spaces, in contrast to the spaces between particles/molecules of water. Many students may not be able to accept or visualise the particulate model at first, even with the use of physical models.
2. To provide evidence that there are spaces between particles, you could demonstrate the mixing of water and alcohol. (For a description of this experiment, see 'Notes for Teachers' on the page 30.)
3. Evidence for the movement of particles comes from diffusion experiments, such as those discussed on page 34 of the Textbook. To demonstrate diffusion, you may bring an object with a strong smell, such as a bottle of perfume (or a durian) into the classroom. Ask students to raise their hands once they are able to smell it. Successive hands will go up as the particles diffuse through the air in the room (this will not work if fans are on).

   A picture can be drawn to show the idea of perfume (or durian) particles moving between the air particles (see diagram "Diffusion of Perfume" on the right).



Diffusion of Perfume

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4. In the laboratory, the diffusion of bromine can be demonstrated (see Figure 3.6 on page 39 of the Textbook). Show the class the gas jars with the glass cover in place. Ask the class to predict what will happen when the bromine and air are allowed to mix. Emphasise that the movement is natural and that no help (e.g. by wind) is given. The diffusion of the gases is usually complete in about 40 minutes.

   In Figure 3.2, the denser bromine is placed in the lower gas jar. If it were in the upper gas jar, students might think that it was gravity that caused the bromine particles to move downwards and mix with the air particles. (Discuss this point with the class.)

5. To show how the rate of diffusion depends on the mass of particles, the experiment shown in Figure 3.8 on page 36 of the Textbook could be demonstrated. (See 'Notes for Teachers' on the next page for details on how to carry out this demonstration.)

6. From what has been covered so far, discuss the importance of evidence in science and summarise evidence for the kinetic particle theory of matter. Encourage students to continually ask the question "What evidence is there for …?" throughout this course.

(page 36)

Mystery Clue

Faster as the average speed of the water molecules is faster in warm water than in cold water. Therefore on collision, the pollen grains will move faster..

IT Link

1. Animation of particle model of the diffusion of gases:
   http://www.mindset.co.za/resources//0000022451/0000029550/0000029490/default.htm
   http://www.media.pearson.com.au/schools/cw/au_sch_lewis_cw1/int/GasDiffusion/0510.html
2. Animation of particle model of the diffusion of a liquid, including the dissolving of a solid (sugar) in water:
   http://highered.mcgraw-hill.com/sites/0072495855/student_view0/chapter2/animation_how_diffusion_works.html

Chemistry in Society (page 35)

Diffusion is All Around Us

Answers to Questions

1. Examples of diffusion: The (pleasant) smell of cooking food. The (unpleasant) smell of rotting food. Smells in restaurants, offices and factories. Perfume. The movement of smoke (on a calm day).
2. Place a loaf of fresh bread in a closed room that is perfectly calm and that people in the room do not move around. After a short time, the smell will be detected through the room due to diffusion and not to wind currents.

Chemistry Inquiry (page 36)

Where is the Evidence?

Group Discussion

1. From the results of experiments.
2. No. In science, all hypotheses and theories are tentative. While they may be able to explain the results of all experiments done so far, they might not be able to explain those of the next experiment! In that case, the hypothesis or theory is modified or discarded.
3. (a) Diffusion experiments. (b) Mixture of water and alcohol. (c) Gases, but not solids, can be compressed. Refer to experiments students probably did in Lower Secondary Science to show these.

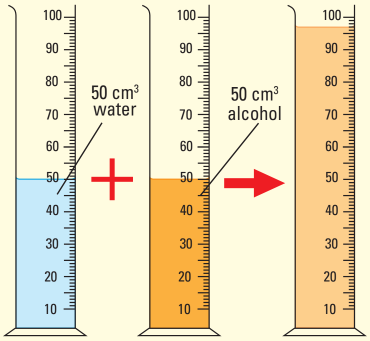
Skills Practice (page 37)

1. The sugar is made up of sugar particles (molecules) which are in motion. When added to water, the solid begins to dissolve. Individual particles of sugar move through the water (from the solid sugar where they are concentrated to areas of lower concentration). Diffusion continues until all the sugar particles are evenly dispersed throughout the water. [See again the video animation above for this process.]
2. The rate of diffusion is greater at a higher temperature. Thus the tea particles from the bag in the hot water diffuse through the water faster.

Notes for Teachers

Evidence for spaces between particles

Place some alcohol and water in separate measuring cylinders and note the volumes. Mix the two liquids and note that the total volume is a little less than the combined volume of the two separate liquids.



From this experiment, it can be inferred that water and alcohol consist of particles of different sizes. There are spaces between the particles and on mixing, the smaller of the two kinds of particles occupy the spaces between the larger particles, resulting in a smaller total volume. (Note that which liquid has the smaller particles cannot be inferred from this experiment.)

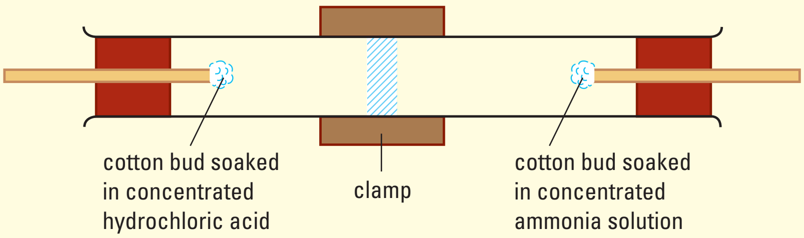
An analogy to this experiment is mixing rice and beans together. The smaller rice grains fit between the larger beans and so the volume of the mixture is less than the sum of the volumes of the rice and beans.

Notes:

1. As alcohol (ethanol) is rather expensive, cheaper meths (methylated spirit) or isopropyl alcohol (rubbing alcohol) can be used.
2. When mixing rice and beans, be sure to tap the container gently on the bench to get the particles to settle, otherwise the total volume may not be less than the volume of the rice and beans. Instead of rice and beans, any particles of differing sizes can be used, e.g., sand, groundnuts, broad beans, mung beans or dried peas.

Experiment to show that rate of diffusion of gas particles depends on their mass

Set up the apparatus as shown in the diagram below. A suitable glass tube is one with a length of about 60 cm and a diameter of about 3 cm. If a much longer tube is used, the white ring takes too long to form and is too spread out. The glass tube must be perfectly dry and there must be no draughts in the room (ensure the fans are switched off).



- Clamp the glass tube horizontally.
- Soak a piece of cotton bud in concentrated hydrochloric acid. The acid produces hydrogen chloride gas.
- Soak another piece of cotton bud in concentrated ammonia solution. The solution produces ammonia gas.

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- Push the soaked cotton buds into the ends of the tube simultaneously and then close them with rubber bungs. After a few minutes, a white ring of solid ammonium chloride appears inside the glass tube.

Speed of gas particles (molecules)

The average speed of individual gas particles when not colliding is about 500 m/s. (Compare this with the average cruising speed of an MRT train which is about 15 m/s and a jet airliner which is about 250 m/s.) For example, in Figure 3.2 on page 34 of the Textbook, the rate of diffusion of the bromine gas in air (at normal atmospheric pressure) is only about 1 m/s. This is much slower than the speed of individual bromine molecules as the bromine molecules and molecules in the air collide with each other, thus changing their direction of movement all the time. Think of a person trying to move quickly along a crowded footpath. Although his movement is quite fast, the other people make his overall progress relatively slow.

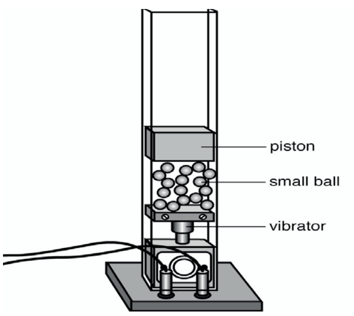
IT Link

Effect of molecular mass of gas particles on speed and pressure:
http://mutuslab.cs.uwindsor.ca/schurko/animations/avogadro/avogadro.htm

Teaching pointers

3.3 What are the Particulate Models of Matter? (page 36)

1. From the kinetic particle theory of matter, specific models are used to explain the structure of solids, liquids and gases. The need to visualise the movement of particles is important. Hence, a kinetic motion model could be demonstrated (see below).



To use the model, begin with a low voltage so that the balls vibrate slowly to simulate the movement of particles in a solid. Slowly increase the voltage to speed up the movement of the small balls. This simulates the movement of particles in a liquid. Increase the speed of the vibrator so that the balls move very fast and occupy a large space to simulate the movement of particles in a gas.

If the school laboratory does not have a kinetic motion model, students can still visualise the movement of particles through the animations at the following website:
http://www.harcourtschool.com/activity/states_of_matter/

2. Emphasise to students that the particulate model of matter is important because it enables explanations to be given for many phenomena. Such as changes in state discussed in Section 3.4. An additional 'Chemistry in Society' on 'Using the particulate models of matter' is included at the end of this chapter on this topic. It can be photocopied and distributed to students.
3. Remind students about models in science and the need to continually revise models when they become inconsistent with new observations. More able students could then do Additional Activity 1, which is found at the end of this chapter, to predict how temperature and the mass of the gas particles affect gas pressure. Then, by means of simulated experiments, they will check their model and, if necessary, modify it to explain what they actually observed happening.

(page 38)

Mystery Clue

They would appear to move in a zig-zag or random manner.

Chemistry in Society (page ??)

Using the particulate models of matter

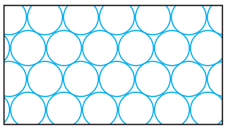
1. For solid structures, compare the shape of a crystal with a model of a crystal made from spheres. Get students to appreciate that the faces, sharp points, straight edges and geometrical shapes of crystals are due to the close arrangement of particles. This can be done using a large crystal of rock salt or a quartz crystals and a pile of polystyrene spheres. Refer to the diagram for sodium chloride crystals
2. When discussing the particle explanation for densities, the teacher might also ask the class why a hot gas has a lower density than a cold gas. (Particles are further apart which increases the volume and decreases the density.)

Answers to Questions

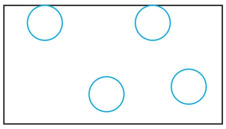
1. In a solid, the particles occupy fixed positions, which means the shape of a solid is also fixed. In a liquid, the particles are free to move, which means the shape of a liquid can change.
2. On heating, the distance between the particles increases. Therefore the volume increases.
3. In gases, the particles are far apart and are able to move closer together when a gas is compressed. The particles in solids and liquids are packed close together and so cannot move much closer.

Skills Practice (page 38)

1. (a)



(b)



2. In a liquid, the particles (molecules) are close together. When liquid water boils and turns into steam, all the particles move far apart from each other to increase the volume. (The volume of a liquid increases about 1000 times on boiling.)

3. (a) Liquids consist of particles that are close together but do not occupy fixed positions. Thus, a liquid does not have a fixed shape. The particles in a liquid are packed closely together and cannot move closer anymore. This means that a liquid has a fixed volume.

(b) Solids have a much smaller volume than an equal mass of gas. The particles in a solid are packed close together while the particles in a gas are far apart. As density is defined by the mass of a substance over its volume, a smaller volume will result in a higher density.

4. (a) The particles in a liquid are close together. The particles in a gas are far apart and occupy the volume of the container.

(b) On a warm day, the particles have more energy and move faster. Therefore, they escape faster through the holes in the balloon, resulting in a faster shrinking of the balloon.

5. (a) In the simple models, particles are represented as solid spheres/balls. As students will learn later, particles can be atoms, molecules or ions.

(b) E.g. The models can explain why gases have much lower densities than solids.

(c) Cf. the examples in Additional Exercise 1.

Notes for Teachers

Theories and models in Science

Theories: Scientists suggest hypotheses and do experiments to test these hypotheses. A hypothesis or a set of hypotheses that has been tested, explains facts well, and is widely accepted is called a **theory**. A theory is usually described using words, diagrams or mathematical formulae. Theories are general and cover many ideas. Thus, the theory of matter describes all matter, and not just solids, liquids or gases.

Models: To explain a particular idea, for example solids, ideas from a theory are used to construct a **model**. A model consists of anything that helps in the understanding of the idea. It can be in the form of words, diagrams, physical models, formulae and equations. The diagrams and text in Table 3.2 on page 36 of the Textbook shows models a person might construct for solids, liquids and gases.

Theories and models explain known facts. However, they must also be able to predict and explain new facts. If they cannot do this, scientists modify them until they can. If this is not possible, they are discarded and new ones are proposed. Therefore, theories and models are never fixed but are always changing and improving. In this way, scientific knowledge grows and becomes more accurate.

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IT Link

For additional information, teachers may find the following websites useful.

1. States of matter plus animations of ice, water and steam: http://www.visionlearning.com/library/module_viewer.php?mid=120
2. Models in Science and what makes a good model: http://www.learner.org/channel/courses/essential/physicalsci/session2/closer1.html
3. Pictures of the three states of water with particle models: http://cwx.prenhall.com/petrucci/medialib/media_portfolio/text_images/FG01_06aC.JPG http://mutuslab.cs.uwindsor.ca/schurko/animations/phasesofmatter/phasesofmatter.html
4. Animation of flow of particles in solids, liquid and gases http://mutuslab.cs.uwindsor.ca/schurko/animations/phasescontainers/phasescontainer.html
5. Motion of particles in solids at different temperatures http://mutuslab.cs.uwindsor.ca/schurko/animations/particlesinmetals/eqilibrium-v1.htm

Teaching pointers

3.4 How Does the Kinetic Particle Theory Explain Changes in State? (page 39)

1. In Chapter 2, melting points and boiling points were introduced as a way of identifying substances. In this section, the changes of state themselves are investigated.
2. Discuss everyday examples of melting. Get the class to refer to Table 3.4 on page 39 of the Textbook to appreciate the wide range of melting points of substances (elements and compounds).
3. *Melting point*: Strictly speaking, this is the temperature at which the solid and liquid phases of a given compound or mixture have the same vapour pressure. However, this definition is not appropriate at 'O' Level. In practice, the melting point is the temperature at which a substance changes from the solid state to the liquid state. (Do not define the melting point as "the temperature at which a substance melts" as *melts* is too close to *melting* to make a good definition.)
4. Explain melting in terms of the particulate models of matter. Let students watch an animation of melting on the Internet or a CD-ROM to see what happens to the particles during melting (and also boiling). Refer to the 'Notes for Teachers' section on page 15 for possible websites.
5. Discuss 'quick frozen' foods and link them with the idea of how crystal size depends on the speed of freezing, which may have been discussed in Chapter 2.
6. A boiling point determination may be demonstrated. Although Figure 3.16 on page 42 of the Textbook refers to the boiling point determination of 1,1,1-trichloroethane, it should not be used in the demonstration as it is a harmful substance (see 'Notes for Teachers' on page 36). Ethanol, with a boiling point of 78 °C, is a suitable alternative. If fractional distillation was taught in Chapter 2, then propanone (boiling point 56 °C) can be used.
   Note: There is a fire risk with ethanol and propanone.
7. Explain the reason why a burn from steam at 100 °C is more serious than a burn from boiling water. This is because during the change of state from water to steam at 100 °C, additional heat is absorbed. This heat is then given out when steam touches a cool surface such as a hand.
8. Get the class to predict the physical states of substances at room conditions, given their melting and boiling points (see question 5 in Skills Practice on page 44 of the Textbook). Using 25 °C as room temperature, then:
   - if the boiling point is below 25 °C, the substance is a gas.
   - if the melting point is above 25 °C, the substance is a solid.
   - if the melting point is below 25 °C and boiling point is above 25 °C, the substance is a liquid.
9. **Note:** On page 43 of the Textbook, under the heading 'Condensation', in the sentence 'Many useful gases are condensed to liquids for storage and transportation because a liquid has a smaller volume', note that the comparison is made between a liquid and an equal mass of gas.
10. **Evaporation:** Get students to place a drop of ethanol or ether on the back of their hands. They should note that their hands feel cooler. This is because the heat needed to evaporate the liquid is taken from the hand, which therefore feels cooler.

Experiment 3.1 (PWB page 39)

Students can investigate the temperature changes during melting. Stearic acid (m.p. 69 °C) is a safe substance to use and it melts in hot water. Therefore, if a supply of hot water is made available, a Bunsen burner is not needed to heat the water. The experiment has skills useful for SPA practice including use of tables, drawing and interpreting graphs and identifying sources of error.

Possible extensions/alternatives to Experiment 3.1

1. As an extension, a freezing point determination of stearic acid can be carried out. After the melting point determination, allow the stearic acid to cool in air and again take measurements of temperature and time. By drawing a graph, students can obtain the freezing point and appreciate that it is the same as the melting point. Alternatively, just carry out the freezing point determination by placing a boiling tube of stearic acid in hot water until it melts then remove it and allow it to cool in air. Freezing point determination is much easier to obtain than melting point determination but it takes a longer time.

   Note: Naphthalene (literature melting point value of 80.6 °C), should not be used as an alternative to stearic acid as it is carcinogenic.

2. An alternative to stearic acid is to use acetophenone (phenylethanone) which has a melting point of 19 °C. Half-fill a beaker with a mixture of cold water and crushed ice. Place about 4 cm^3 of acetophenone in a boiling tube and add a thermometer. Place the boiling tube in the beaker.

Exercise 3.2 (TWB page 19–20)

IT Link

Animation of the spacecraft descending by parachute to surface of Titan:
http://news.bbc.co.uk/1/shared/spl/hi/sci_nat/04/cassini/html/titan.stm
Photographs of the surface of Titan:
http://news.bbc.co.uk/1/hi/in_pictures/4194941.stm

Skills Practice (page 44)

1. E.g. Melting of ice. Melting of foods such as ice cream and butter. Thawing of frozen foods (due to the melting of ice). Melting of metals such as gold. Melting of wax in a burning candle. Freezing of water in a refrigerator. Liquid candle wax changing to solid wax.
2. Large ice crystals rupture the cells walls allowing the cell contents to come out.
3. The rough surface of the porcelain chips or stones allows bubbles of gas to form steadily, thus preventing the sudden formation of gas bubbles which causes the contents to jump or bump.
4. (a) Water takes heat from the body to evaporate leaving the body feeling cooler.
   (b) The solid dry ice sublimes, changing directly to a colourless gas.
5. (a) **A** (b) **B** (c) **C** (it will melt)
   (d) **D** (e) **A** (it is a gas)

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Notes for Teachers

Figure 3.16: Use of 1,1,1-trichloroethane (TCA)

It is now known that 1,1,1-trichloroethane is an ozone-depleting substance in the environment and contributes to ground smog formation. TCA may also affect human health by causing respiratory and circulatory paralysis, including loss of consciousness, numbness and slowing down reaction time. The use of TCA in developed countries has been prohibited since the beginning of 1996 under the Montreal Protocol. TCA may be available in some schools but its purchase is now limited.

IT Link

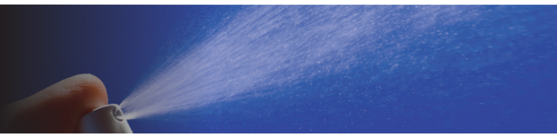
Changes of State

Movie showing changes of state — animations and graphs
http://cwx.prenhall.com/petrucci/medialib/media_portfolio/text_images/031_ChangesState.MOV

Animation of changes of state of water with particle models
http://mutuslab.cs.uwindsor.ca/schurko/animations/waterphases/status_water.htm

States of elements in the Periodic Table at temperature changes
http://mutuslab.cs.uwindsor.ca/schurko/animations/phasetransitions/phase.htm

03 Chapter Review



Self-Management

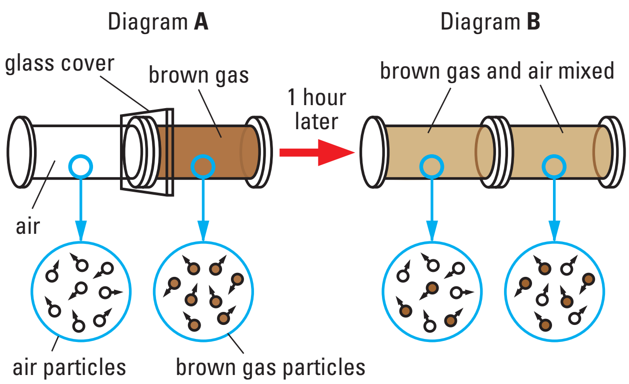
Misconception Analysis (page 45)

1. **True** Solids have a fixed volume. This is because the particles in a solid are packed close together and occupy fixed positions.
2. **True** This is because the particles are already packed close together and there is very little empty space between them.
3. **False** Gas particles move faster as the temperature increases and as the mass of the particles decreases.
4. **False** The particles stay the same size, but the distances between the particles decrease.
5. **True** The heat energy absorbed is used to separate the particles in the solid rather than to raise the temperature of the solid.
6. **False** Evaporation occurs only at the surface of a liquid and is slow; boiling occurs throughout the liquid and is faster.

Practice

Structured Questions (page 45 – 46)

1. (a) (i) The brown gas and air are mixed. The colour became a paler brown.
   (ii) Diffusion
   (b) (i) The air and brown gas particles are moving.
   (ii)

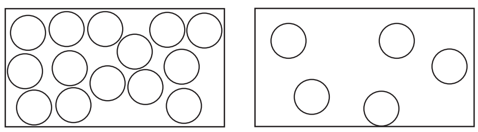


2. (a) **A** and **B** produce gases which move along the tube and react when they meet.
   (b) Particles of **A** are heavier as they move more slowly and cover a shorter distance.
   (c) The speed of diffusion of gas particles depends on their mass: the larger the mass, the slower the particles diffuse.

3. (a) The particles in a solid are closely packed and cannot move closer. Solids therefore cannot be compressed. The spaces between the particles in a gas are large and so the gas can be easily compressed.
   (b) When heated, the particles in a solid still remain very closely packed. The particles in a liquid, though still packed closely, have some freedom of movement and so are able to move apart further, that is, expand more.

4. (a) Similarities: Heat energy is absorbed; temperature stays constant; particles become more disorderly.
   (b) Differences: Particles stay close together in melting but go far apart in boiling; bonds between the particles remain in melting but are completely broken in boiling.

5. (a)



700 °C   1300 °C

   (b) (i) At 700 °C, the substance is a liquid; at 1300 °C, it is a gas.
   (ii) The particles are much closer together at 700 °C than at 1300 °C.

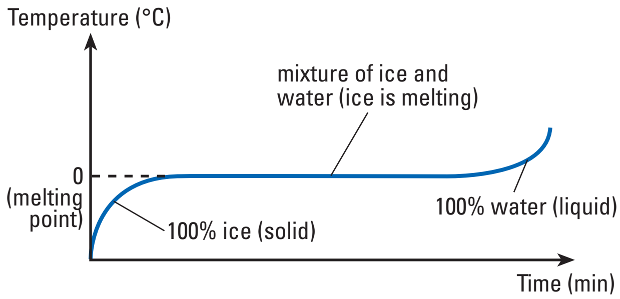
6. (a) (i) Easy to obtain; ice cream is not too cold.
   (ii) No liquid produced on subliming, so no mess.
   (b) Ice because solid carbon dioxide would freeze the drink solid and perhaps burst the cans.

7. (a) 65 °C
   (b) (i) Z   (ii) Y
   (c) Heat energy is released during freezing. As this happens, the liquid particles move more slowly and come closer together to form a solid. Only when all the liquid has frozen does the temperature begin to decrease further.
   (d) The first crystals of solid would appear.

Free Response Question (page 46)

1. (a) In the solid state, the particles are arranged orderly in a fixed pattern. When heated, the particles gain energy and move further apart. The orderly arrangement of particles breaks down and a liquid forms with the particles able to move about more freely. With further heating, the forces holding the particles in the liquid are overcome. The particles separate further, escape from the surface of the liquid and form a gas. In the gaseous state, the particles move about randomly at high speeds.

   (b)



2. The helium particles have a very small mass and move very quickly to escape through holes in the balloon (they diffuse more quickly). The neon particles have larger masses and diffuse more slowly, so less neon escaped. The argon particles have the largest mass and so diffuse the most slowly that almost no argon has been able to escape.

Extension (page 47)

1. Big icebergs regularly break off from the Antarctic ice sheet. They consist of pure water. Melting and loss of water would be a major problem in towing an iceberg to Singapore. It might have to be covered with insulation for the journey. Also, the iceberg might break up during the journey, which apart from the loss of ice, would be a hazard to ships. Scientists have seriously suggested towing big icebergs to Saudi Arabia.
   Melting the iceberg in Singapore would absorb heat and this could be used to cool buildings.

2. (i) For example, caesium (m.p. 29 °C) and gallium (m.p. 30 °C).
   (ii) Liquids have a much lower volume than an equal mass of gas. Thus more oxygen can be transported in the liquid state.
   (iii) Liquid nitrogen is used to freeze and kill/destroy skin growths, such as warts and some forms of skin cancer. It is also used to preserve medical specimens such as sperm and animal embryos.
   (iv) The orange areas are probably covered by sulfur or a mixture containing sulfur. The lake areas will be warm, which is in contrast to the temperature on Io's surface which is about –143 °C.
   (v) They are safer in case the thermometer breaks. Mercury is toxic.
   (vi) The automated water sprinkler systems are set at a low temperature (about 68 °C). Heat given off by a fire heats the sprinkler. When the sprinkler opens, water flows out in a spray pattern.

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Additional Teaching Material

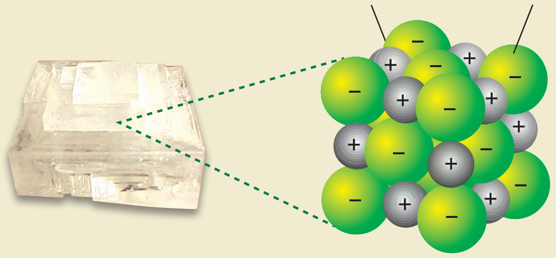
Chemistry in Society

Using the particulate models of matter

In science, good theories and models can explain many observations. They can also be used to make predictions. The particulate models of matter in the Textbook are good models as they are able to do this. Some examples are discussed below.

1. **Structure of crystals**

   In solids, the particles are packed closely together in an orderly arrangement. That is why crystals have flat faces, straight edges and sharp points. You can see this in the model of a crystal as shown. Compare the model with the crystals of sodium chloride.

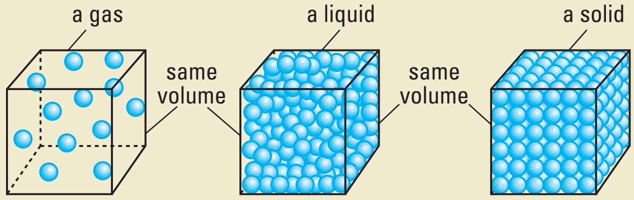


Sodium chloride crystal and its model

The shape of the model is due to the orderly arrangement of the spheres. The shape of the crystal is due to a similar orderly arrangement of particles.

2. **Densities of solids, liquids and gases**

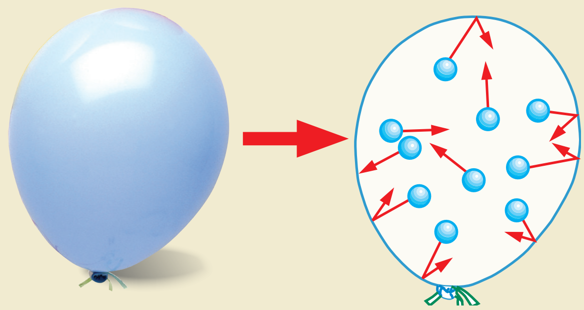
   Look at the diagrams below. The gas has fewer particles than an equal volume of a solid or a liquid. Therefore the density of a gas (mass per unit volume) will be much lower than the density of a solid or a liquid. For example, the density of air is just 0.0013 g/cm^3 while the density of gold is 19.3 g/cm^3.



Using the particle models of matter to compare the density of gases with liquids and solids

3. **Gas pressure**

   Gases exert a pressure on the container. Look at the diagram below. The air in the balloon pushes against its inner walls. This is explained using the particulate models of matter. The gas particles are continuously moving. As they move, the particles hit the walls, exerting a force. Blowing more air into a balloon increases the number of particles hitting the walls, thus increasing the pressure.



Gas pressure

Can you use the model to predict how temperature and the mass of the gas particles affects gas pressure? You can investigate this question by doing Additional Exercise 1.

Questions

Use the particulate model to explain the following:

(a) Solids have a fixed shape but liquids do not.

(b) A substance expands when heated.

(c) Gases are easily compressed but liquids and solids are not.

Additional Teaching Material

Chemistry in Society

Ice-storage systems in Singapore

Several years ago, the Navy wanted to reduce the cost of air-conditioning at its Changi base. How did they solve this problem?

The problem was solved using the energy change that takes place during melting. With cheap night-time electricity, water is frozen into ice in special refrigeration units. The ice is stored in rooftop tanks and allowed to melt during the day, absorbing heat and keeping the buildings cool. The ice-storage systems share the load of air conditioning demands during the day, thus reducing the consumption of expensive day-time electricity. This technique has saved $1 million in equipment and also up to $200 000 a year in electricity charges.

Making ice during the night is possible because of cheaper electricity rates. In Singapore, three types of electricity are supplied. These are low tension, high tension and extra high tension. The low tension electricity is supplied to both residential and non-residential areas and costs the same during the day and the night. High tension and extra high tension electricity are supplied to industrial areas and is cheaper during the off-peak hours (11.00 pm to 7.00 am) than during the peak period (7.00 am to 11.00 pm).

An ice-storage tank in use at Changi Naval Base.

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Additional Teaching Material

Additional Exercise 1: A Scientific Model for a Gas

Objective
To develop and use a particle model for particle motion and gas pressure

Competencies
CIT: creativity *(developing and testing a model);* ICS: IT *(simulation)*

To understand ideas in science, we construct models. The models can consist of words, diagrams, formulas, mathematical equations and physical models — anything that helps our understanding of the ideas.

Models are used to explain known facts and to predict new ones. Models are never fixed, but are changed when they cannot explain predictions or new observations.

In this activity, you will develop a particle model and use it to make predictions. Then, you will check the predictions and see if your model needs to be changed.

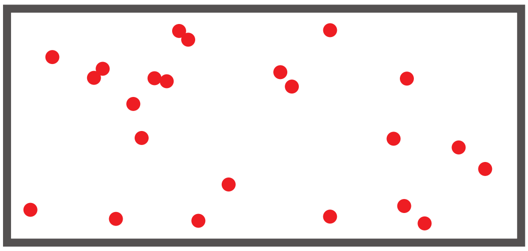
A Developing a model of particle motion and gas pressure

1. The diagram below represents the simple model of a gas

   State two features of this model of a gas.

   ____

   ____



You will now extend this simple model to include ideas about gas pressure.

2. Particles of gas exert a pressure on the walls of the container. Use the model to explain how this happens.

   ____

   ____

3. Different factors can change the gas pressure. Predict, with reasons, how the following factors will change the gas pressure:

   (a) An increase in temperature.

   ____

   ____

   (b) An increase in the mass of the particles.

   ____

   ____

(c) An increase in the number of particles.

____

____

A Developing a model of particle motion and gas pressure

1. The diagram below represents the simple model of a gas

   State two features of this model of a gas.

B Checking the model

To check the model you have constructed, you will use a computer animation that simulates the motion of gas particles in a container. A useful website is: http://chemconnections.org/Java/molecules/index.html

Your teacher will show you how to open the file for the animation.

1. (a) Increase the temperature of the gas. Look at the 'pressure meter' to see how the gas pressure changes.

   What happens to the gas pressure?

   ____

   Is your prediction correct?

   ____

   (b) Increase the mass of the particles.

   What happens to the gas pressure?

   ____

   Is your prediction correct?

   ____

   (c) Increase the number of gas particles.

   What happens to the gas pressure?

   ____

   Is your prediction correct?

   ____

2. Vary the three factors to find out the one that has the greatest effect on gas pressure.

   Which factor has the greatest effect?

   ____

   ____

3. If any of your predictions are wrong, modify your model so that it correctly explains the observations.

   ____

   ____

   ____

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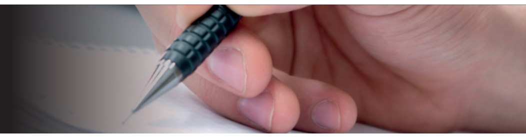
Additional Teaching Material



Additional Exercise 2: Comparing Condensation and Freezing

Objective
To compare two changes of state

Competencies
CIT: comparing

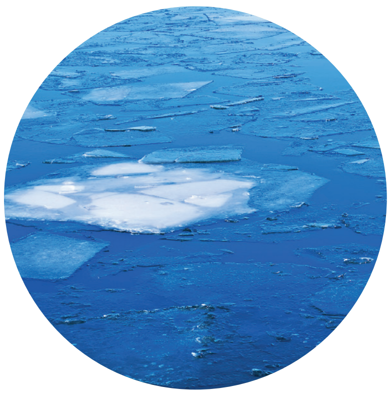
Condensation and freezing are two changes of state. List the ways in which these changes are **similar** and the ways in which they are **different**.

Condensation → Similarities ← Freezing

Similarities

Differences

condensation



freezing

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